Materials Characterization Paper
In Support of the
Advanced Notice of Proposed Rulemaking –
Identification of Nonhazardous Materials That Are Solid Waste

Biomass - Forest Derived Biomass and Pulp and Paper Residues

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1. Definitions of Forest Derived Biomass and Pulp and Paper Residues

The forest products industry generates large amounts of residual biomass as timber is harvested and manufactured into marketable goods such as lumber and paper. Forest derived biomass may originate directly from the forest (logging residues) or from timber processing mills (primary mill residues). Logging residues include tree tops and small branches that are typically left uncollected during logging operations. Primary mill residues consist of bark residues, coarse residues such as chunks and slabs, and fine residues such as shavings and sawdust generated at sawmills that process harvested timber. Other forest derived biomass produced by this industry include residues from woodworking shops, furniture factories, and truss and pallet manufacturing (secondary mill residues). These materials have typically been used for their fuel value in paper operations, as well as disposed of in landfills.[1]

Another source of biomass fuels from the forest products industry is pulp and paper residuals, including black liquor and wastewater treatment sludges. Black liquor is generated in the kraft process, which in 2000 accounted for 83 percent of domestic pulp production. Black liquor consists of lignin and pulping chemicals used to separate lignin from the cellulosic fraction of wood. Sludges, both primary and secondary, are produced from wastewater treatment of process effluents. Primary sludges originate from primary wastewater treatment operations (i.e., sedimentation or primary clarification operations) and consist of wood fiber and inorganic materials, while secondary sludges come from secondary / biological treatment operations and are composed largely of microbial biomass. Note that use of sludges associated with municipal wastewater treatment (i.e., sewage treatment) plants as fuel is addressed in a separate paper.

2. Annual Quantities of Forest Derived Biomass and Pulp and Paper Residues Generated and Used

(1) **Sectors that Generate Forest Derived Biomass and Pulp and Paper Residues:**

- NAICS 113310: Logging
- NAICS 3221: Pulp, Paper, and Paperboard Mills

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[1] Other materials are sometimes identified as Forest Product Industry (FPI)-derived fuels in the literature; these include wood products found in bales of cardboard (old cardboard container, or OCC, rejects), turpentine and derivatives, biogases recovered from industrial waste water treatment systems or landfills, methanol from strippers, and "tall oil" from pine processing. These are not discussed in detail here for a variety of reasons. In some cases (e.g., biogases and turpentine) they are included in other discussions. In other cases, it is not clear whether the materials are already considered part of another material (e.g., OCC rejects) or are used as fuel with any frequency (e.g., tall oil).

- NAICS 32111: Sawmills and Wood Preservation
- NAICS 32121: Veneer, Plywood, and Engineered Wood Product Manufacturing

(2) **Quantities and Prices of Forest Derived Biomass and Pulp and Paper Residues Generated:**

- Perlack *et al*. (2005) estimated production of logging and other removal residues at 67.1 million tons[2], 41.9 million tons of which is available for recovery. This is consistent with Milbrandt (2005), who estimated total production at 62.4 million tons. McKeever (2004) estimated total production at 103 million tons with 92.6 million tons available for recovery. Unlike the other two studies, McKeever included 17.6 million tons of stumps and limbs. Each of these three studies was derived from the USDA Forest Service's Timber Product Output Database.
- Total primary mill residue production ranges from 86.8 to 91.4 million tons (McKeever 2004, Perlack *et al.* 2005, Milbrandt 2005).
- Pulp and paper mills produce the dry biomass equivalent of 52.1 million tons of black liquor (Perlack *et al.* 2005) and between 4.2 and 5.8 million tons of wastewater treatment sludges (ITC 2002, Thacker 2007).
- Gan (2007) estimates for forest residue a median total market price (including transport) of $40 per dry ton with a range from $36 to $45. Current prices for primary mill residues are undetermined, although there is evidence to suggest that prices have increased substantially in recent years (*e.g.*, sawdust priced at $25 a ton in 2006 to over $100 per ton in some markets in 2008) (Millman 2008).
- No established commercial market for black liquor exists as it is utilized within pulp and paper mills. Prices for sludges are undetermined.

(3) **Trends in Generation of Forest Derived Biomass and Pulp and Paper Residues:**

- Domestic primary mill residue production decreased from 113.4 million tons in 1990 to 83.4 million tons in 2002 (McKeever 1999, Smith *et al.* 2004).
- Domestic pulp and paperboard capacity decreased at an average annual rate of 0.7 percent for the period from 2000 to 2007 (AF&PA 2008).
- US timber harvest is expected to increase 24 percent by 2050 according to the Fifth Resources Planning Act Timber Assessment (Haynes and Skog 2002). This increase will be exclusively in the harvest of nonsawtimber trees.
- Perlack *et al.* (2005) predict that by 2050 increases in availability of logging and other removal residues by 23 million tons, pulping liquors by 22 million tons, and primary and secondary mill residues by 16 million tons. An additional 60 million tons of forest biomass may also be available should widespread fuel treatments for reducing fire hazards be implemented.

3. Uses of Forest Derived Biomass and Pulp and Paper Residues

(1) **Combustion Uses of Forest Derived Biomass and Pulp and Paper Residues:**

- Logging residues, as defined by the Timber Product Output Database, are not currently collected for combustion or non-combustion use.
- Primary mill residues tend to be clean, uniform, concentrated, and with a low-moisture content (Perlack *et al*. 2005). They are, therefore, highly desirable as a

[2] Biomass production estimates are presented on an annual basis.

fuel as well as for other purposes. Currently, only between 1.7 and 1.9 million tons are unused (McKeever 2004, Perlack *et al.* 2005, Milbrandt 2005).

- Approximately 42 percent of all primary mill residues are used as fuel, including 76 percent of bark residues, 12 percent of coarse residues, and 56 percent of fine residues (Smith *et al*. 2004).
- Essentially all black liquors produced in pulp and paper operations are combusted as fuel in pulping liquor recovery furnaces. These furnaces provide process energy and recover pulping agents (e.g., sodium sulfide) used to form fresh cooking liquor (Perlack *et al.* 2005, Carrott and Carrott 2007).
- In 2002, 21.9 percent of pulp and paper mill sludges were combusted as fuel (Thacker 2007). An undetermined fraction of sludges was used as a cement kiln feedstock and as a fuel pellet ingredient.
- It has been estimated that thermal oxidation of paper sludge can supplement as much as 11 to 34 percent of fossil fuel demand for a medium size mill. (CANMET Energy Technology Centre 2005.)

(2) **Non-Combustion Uses of Forest Derived Biomass and Pulp and Paper Residues:**

- Logging residues left on harvested timberland help control erosion, replenish nutrients, and maintain soil productivity. It is unknown what fraction can be removed without disrupting these benefits, and this is likely to vary by location.
- Around 56 percent of primary mill residues are used for non-combustion purposes. This includes 20 percent of bark residues, used largely for shredded mulches, and 78 percent and 23 percent of coarse and fine residues, respectively, used for woodpulp, nonstructural panels, and animal bedding (McKeever 2004, Smith *et al.* 2004). The specific uses are driven by economic considerations.
- In 2002, 14.6 percent of pulp and paper mill wastewater treatment sludges were applied to land as a soil conditioner, fertilizer, liming agent, or mulch (Sippola *et al.* 2003, Thacker 2007). Around 11.7 percent had other beneficial uses, including as papermaking fiber, industrial absorbent, animal bedding, manufactured soil component, compost feedstock, landfill barrier cover (Zule *et al.* 2007), acid mine drainage control cover, building board/fixture (Scott *et al.* 2000), glass or lightweight aggregate, and brick or concrete additive (Naik 2004, Thacker 2007). Sludges are also being considered as a feedstock for ethanol production (Fan and Lynd 2007).

(3) **Quantities of Forest Derived Biomass and Pulp and Paper Residues landfilled:**

- Of the residues described in this section, only pulp and paper mill wastewater treatment sludges are landfilled to any appreciable extent.
- In 2002, approximately 51.8 percent of sludges were disposed of in landfills or lagoons, typically onsite (Thacker 2007, ITC 2002). There is a trend toward reduced disposal of sludges in landfills largely due to higher landfilling prices and higher fossil fuel prices (Mahmood and Elliott 2006, de Alda 2008).

(4) **Quantities of Forest Derived Biomass and Pulp and Paper Residues Stockpiled/Stored:**

- The amount of logging residues that is uncollected is unknown, and these tend to undergo rapid decomposition after timber harvest.
- Black liquors are cycled through pulp and paper mills on a continuous basis.

- Stockpiled/stored quantities of primary mill residues and pulp and paper mill wastewater treatment sludges are undetermined.

Exhibit 1: Overview of Generation and Use of Forest Derived Biomass and Pulp and Paper Residues

Commodity	**Annual Quantity Generated**	**Annual Quantity Used as Fuel**		**Annual Quantity Landfilled**	**Annual Quantity in Other Uses**	**Total Quantity Stockpiled as of 2007**
		Cement Kilns	**Other**			
	-------------- *Million Tons* ---------------					
Logging Residues	41.9 – 92.6	0	0	0	0	0
Primary Mill Residues	86.8 – 91.4	N/I	35.3	0	46.4	N/I
Black Liquor	52.1	0	52.1	0	0	0
Sludges	4.2 – 5.8	N/I	0.9 – 1.3	2.2 – 3.0	1.1 – 1.5	N/I
N/I = not idetified						

4. Management and Combustion Processes for Forest Derived Biomass and Pulp and Paper Residues

(1) **Types of Units Using Forest Derived Biomass and Pulp and Paper Residues as a Fuel:**

- Forest derived biomass are used as a fuel in a variety of boilers including Dutch ovens, fuel cell ovens, spreader stokers, suspension-fired boilers, and fluidized bed combustion boilers (EPA 2003). Scrap wood may be co-fired with other fuels, primarily coal (Mann and Spath 2001).
- In the kraft pulping process, black liquor is combusted as a fuel in a pulping liquor recovery furnace. Sludges may be combusted as a fuel in hog fuel boilers, as a supplementary fuel, or in fluidized bed boilers (Sell 1992).

(2) **Sourcing of Forest Derived Biomass and Pulp and Paper Residues:**

- Logging and primary milling residues are generated during timber harvest and milling operations.
- Black liquor is spent cooking liquor from the kraft pulping process (EPA 1995). Sludges originate from wastewater treatment and, in the case of mills utilizing discarded paper sources, de-inking processes.

(3) **Processing of Forest Derived Biomass and Pulp and Paper Residues:**

- Logging and primary milling residues may be chipped or sorted before combustion so that they can be efficiently burned as fuel. They may also be dried (cured).

- Black liquor undergoes a series of concentrating steps before being combusted as a fuel. Weak black liquor is first concentrated to about 55 percent solids by a multiple-effect evaporator system, and then to around 65 percent by a direct-contact evaporator or indirect-contact concentrator (EPA 1995, EPA 2002).
- Pulp and paper mill sludges typically undergo mechanical dewatering before being combusted as fuel, with minimum solids content of around 40 percent needed for sustained combustion (Sell 1992, Caputo and Pelagagge 2001). Some sludges are dried to 70 to 95 percent solids (Thacker 2007).

(4) **State Status of Forest Derived Biomass and Pulp and Paper Residues Use as Fuel:**

According to state responses to a 2006 survey by the Association of State and Territorial Solid Waste Management Officials (ASTSWMO 2007), Iowa and Mississippi have approved the use of pulp and paper residue as fuel rather than as a waste. This use in these states has a pre-approved status, suggesting that a case-by-case approval process for designation of beneficial use is not necessary for this use (ASTSWMO 2007, p.B-25). In addition, Michigan reports that in at least one instance the use of pulp and paper residues as fuel has been approved as a beneficial use.

As of September 2006, approximately 50 percent of states had renewable fuels portfolio standards requiring that varying percentages of power generated within the individual states come from alternative fuels (including biomass) by a designated future date; several more states have enacted such regulations since then (DOE 2006).[3]

5. *Forest Derived Biomass and Pulp and Paper Residues Composition and Impacts*

(1) **Composition of Forest Derived Biomass and Pulp and Paper Residues:**

- The heating values of forest derived biomass and pulp and paper residues depend upon moisture content.
- The heating value for dry (0 percent moisture) woody materials[4] is typically between 15.5 and 16.4 million btu/ton (7,750 to 8,200 btu/lb) (Wright *et al.* 2006). Wood fired in the lumber and pulp and paper industries has an average moisture content of 50 percent, with a heating value of between 9 and 10 million btu/ton (4,500 to 4,980 btu/lb) (EPA 2003, EIA 2008).
- The average heating value of dry black liquor is 11.8 million btu/ton (5,880 btu/lb) (EPA 1995), with a range of 11.6 to 13.4 million btu/ton (5,820 to 6,680 btu/lb) (Niemelä and Alén 1999). The heating value of hydrated black liquor as enters the recovery boiler tends to be 20 to 25 percent less (*i.e.*, average 9.1 million btu/ton (4,560 btu/lb) with a range of 9.0 to 10.4 million btu/ton (4,510 to 5,180 btu/lb)) (Niemelä and Alén 1999).

[3] The summary table in the reference does not always specify which types of biomass are included, however, it is likely that woody biomass is included. For example, Nevada specifies "wood".

[4] Also called the gross or higher heating value.

- A mixture of primary and secondary sludges as generated by the pulp and paper industry may have a heating value of 3.6 million btu/ton (1,810 btu/lb) at 63 percent moisture (Tarnawski 2004). Sell (1999) and EIA (2008) describe an average sludge heating value of unknown moisture content of 12.0 and 7.5 million btu/ton (6,000 and 3,760 btu/lb), respectively.

(2) **Emissions Impacts of Using Forest Derived Biomass and Black Liquor as a Fuel:**

- To evaluate the environmental impacts of burning forest derived biomass, we examined the emissions associated with burning wood in a boiler and compared these values to the emissions associated with the combustion of conventional fossil fuels, as summarized in Exhibit 2. The estimates in the exhibit suggest that the combustion of wood results in higher PM emissions than natural gas or distillate oil, but lower PM emissions than coal or residual oil systems. Therefore, they fall within the range of typical fuels. The data in Exhibit 2 also suggest that wood results in lower SO_2 emissions than most conventional fuels. The estimated NOx emissions associated with wood combustion are similar to those associated with distillate and lower than the NO_x emissions for other conventional fuels.[5]
- Combustion of black liquor as a fuel in a recovery boiler with an electrostatic precipitator yields 0.2 lbs. particulate matter per MMBtu. Combustion without pollution controls emits vastly higher particulate matter, ranging upwards of 15 lbs./MMBtu. Regardless of pollution controls employed, SO_2 emissions equal 0.6 lbs./MMBtu, while CO emissions are 0.9 lbs./MMBtu. (EPA 1995, p.10.2-5)

(3) **Lifecycle Emissions Impacts:** Use of forest derived biomass as a replacement for traditional primary fuels may eliminate the environmental impacts associated with extraction and processing of traditional fuels. In addition to the emissions impacts of combustion described above, Exhibit 2 lists the quantities of the total cradle-to-gate emissions for these fuels based on typical processes in the United States in the late 1990s, with wood scrap combustion presented as an indicator of the emissions likely from the combustion of wood debris. Note that there may be impacts associated with the processing of wood debris into useable fuel that are not accounted for in the values presented in Exhibit 2. In addition, there may be alternative uses (e.g., mulching) that are environmentally preferable to combustion.

[5] We note that the emission factors for wood presented in Exhibit 2 represent averages for wood-burning boilers. In addition, the wood reflected in the emissions data may include wood other than forest derived biomass.

Exhibit 2: Comparative Impacts of Wood Combustion versus Alternative Primary Fuels

Pollutant	Wood	Coal		Distillate Fuel Oil		Residual Fuel Oil		Natural Gas	
	Combustion	Combustion	Combustion plus Upstream	Combustion	Combustion plus Upstream	Combustion	Combustion plus Upstream	Combustion	Combustion plus Upstream
	---------------------------- *lb./MMBtu* --------------------------								
Criteria Pollutants									
PM2.5	-	-	-	-	-	-	-	-	-
PM10	0.019	0.054	0.054	0.011	0.011	0.093	0.093	0.009	0.009
PM, unspecified	-	-	0.246	-	0.012	-	0.012	-	0.004
NOx	0.167	0.482	0.504	0.173	0.234	0.367	0.428	0.301	0.417
VOCs	-	0.006	0.014	0.001	0.363	0.002	0.367	0.009	0.524
SOx	0.008	1.446	1.469	0.209	0.394	1.593	1.781	0.073	1.985
CO	1.511	0.068	0.085	0.036	0.082	0.033	0.079	0.058	0.282
Pb	$1.33x10^{-4}$	$8.93x10^{-6}$	$9.19x10^{-6}$	$4.60x10^{-6}$	$5.61x10^{-6}$	$5.80x10^{-5}$	$5.90x10^{-5}$	-	$2.72x10^{-7}$
Hg	-	$2.05x10^{-6}$	$2.14x10^{-6}$	$1.58x10^{-6}$	$1.77x10^{-6}$	$8.67x10^{-6}$	$8.85x10^{-6}$	-	$7.18x10^{-8}$

Source:
Franklin Associates 1998.
Note:
"-" signifies data not available; may equal zero.

The emission information presented in this table is derived from Life Cycle Inventory (LCI) data, as compiled by Franklin Associates. LCI data identifies and quantifies resource inputs, energy requirements, and releases to the air, water, and land for each step in the manufacture of a product or process, from the extraction of the raw materials to ultimate disposal. The LCI can be used to identify those system components or life cycle steps that are the main contributors to environmental burdens such as energy use, solid waste, and atmospheric and waterborne emissions. Uncertainty in an LCI is due to the cumulative effects of input uncertainties and data variability.

There are several life cycle inventory databases available in the U.S. and Europe. For this paper, we applied the most readily available LCI database that was most consistent with the materials and uses examined. These LCI data rely on system boundaries as defined by Franklin Associates, as described in the documentation for this database, available at: http://www.pre.nl/download/manuals/DatabaseManualFranklinUS98.pdf.

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